

ELECTRONIC FUNDAMENTALS

Theory Lesson 27: Detector Circuits

Experiment Lesson 27: Detector Experiments

Theory Lesson 28: TRF Receivers

Experiment Lesson 28: Radio-Frequency Experiments



A SERVICE OF RADIO CORPORATION OF AMERICA
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ELECTRONIC FUNDAMENTALS

THEORY LESSON 27

DETECTOR CIRCUITS

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Theory Lesson 27

INTRODUCTION

In previous lessons, you learned that the only frequencies that can be heard by human beings are those called audio frequencies. The range of these is between 20 and 20,000 cycles per second. At the output of a radio receiver, the loudspeaker or headset can reproduce frequencies within the audio range. At the input of the receiver, however, we have *radio frequency* signals that carry the audio signals. In ordinary (amplitude-modulation) receivers, the frequencies of the input carrier signals range between 530 and 1,650 kc (kilocycles) per second. Somewhere between the input and the output of the receiver, the radio-frequency carrier signals must be discarded, so that only their audio-frequency components can be allowed to reach the loudspeaker. The process by which we get the audio intelligence back from the radio-frequency waves is called *detection*. The position of the detector in a radio receiver is shown in the simplified block diagram in Fig. 27-1.

Before we go further into detection, a few questions should be answered. First of all, why must radio frequency signals be used, when all that we are concerned with are the audio signals? Secondly, by what procedure are the audio and radio frequency signals combined so that they are picked up by the antenna of the receiver? The answers to these questions will help us better to understand the fundamental principles of radio transmission so that we will have the proper background for learning about detectors.

It is possible to radiate audio-frequency signals into space, but it is not practical. Whenever alternating currents flow in a conductor, an electromagnetic field builds up on the positive half-cycle until the maximum point is reached, and then falls back into the wire as the current approaches zero at the end of the first half-cycle. During the negative half-cycle, the electromagnetic field

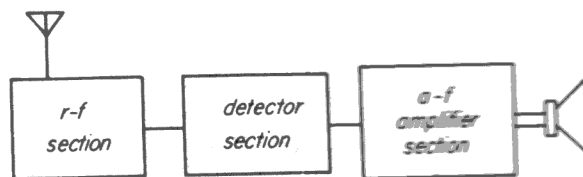


Fig. 27-1

builds up again until the point of maximum current is reached, and then collapses again until the zero point is reached. The only difference between the two half-cycles is the fact that the field has its lines of force pointed in the opposite direction during the negative half-cycle. Not all of the electromagnetic energy returns to the conductor each time the field falls back into the wire. A certain portion of this energy travels into space with the speed of light. But in order for the wire that is radiating this energy to work efficiently, it should be long enough to equal at least one-quarter the length of the wave being radiated. If we wanted to transmit signals of 10,000 cps, for example, the wavelength would be 30,000 meters, or 18.6 miles. A radiating antenna for this frequency would have to be $18.6 \div 4$, or about 4.7 miles long. The lower the frequency, the worse would be the situation, because the wavelength increases as the frequency decreases. To transmit 50 cycles per second, we would need an antenna about 929 miles long.

Even if we could invent a radiator that would work efficiently at audio frequencies without being of impossible length, there would be another factor to consider. The transmitting power required becomes greater as the frequencies are made lower. (Also, greatly increased power is required in order to transmit signals at extremely high radio frequencies. But we are not concerned with these very high frequencies in this lesson). It may be necessary to use 10 kilowatts of power to transmit a radio program operating on an assigned frequency of 760 kc, so that the program will cover a certain territory. To

cover the same territory using a frequency of 10,000 cps, the required power would be tremendously greater.

Audio-frequency signals are not used for electromagnetic wave radiation because of the nature of the audio band itself. We have learned that the audio range is from 20 to 20,000 cps, and that the best radio receiving system is one that can reproduce the entire range. Then we would need a receiver that could tune to the entire band of audio frequencies. At the same time, the broadcasting station would have to transmit the entire audio range, in order for us to tune in the program. The result would be that only one program could be sent out at any one time in the same area. If two or more programs were to be sent out at the same time, they would interfere with each other, and your radio receiver could not possibly select any one of the programs. In order for a radio receiver to tune in only one program at any time, the transmitters must operate at speci-

fic assigned *radio* frequencies spaced at least 10 kc (10,000 cycles) apart from one another. In this way, the radio receiver could be tuned to the assigned radio frequency of the station, and still not have interference from the very next radio station in the broadcast band.

27-1. MODULATION AND DEMODULATION

We have found out why radio-frequency signals must be used for the transmission of radio programs. Now let us learn the method of combining radio and audio signals. R-f signals are easily transmitted, but cannot possibly be heard. The a-f signals can be heard, but not readily transmitted. Our solution is to super-impose the a-f signal on the r-f signal in order that the r-f signal may *carry* the audio signal from the transmitter to the receiver. The process of superimposing one signal on another shown in Fig. 27-2 is known as *modulation*, and the radio-frequency wave is referred to as the *carrier*.

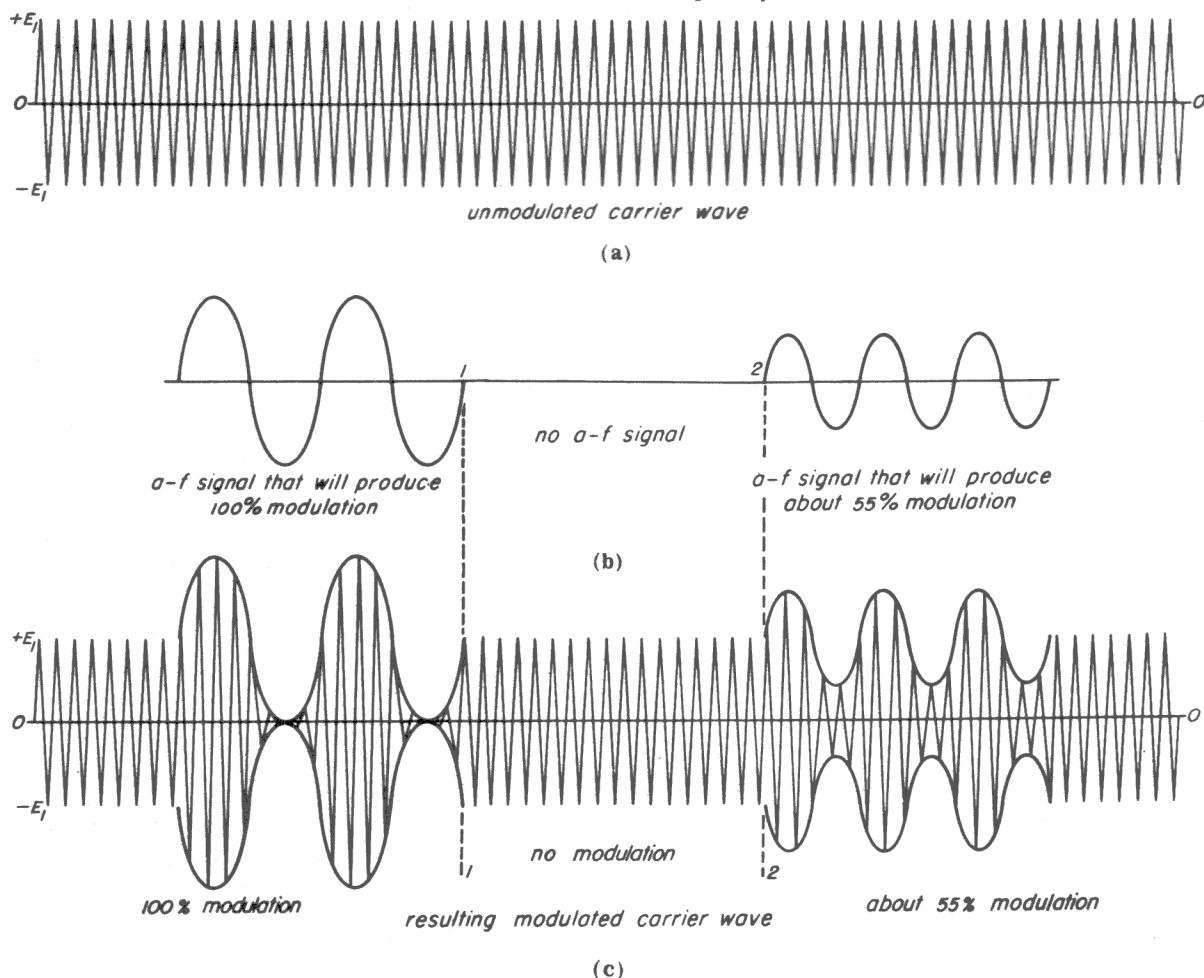


Fig. 27-2

An unmodulated radio frequency carrier is shown graphically in Fig. 27-2a. Assume that the frequency of the carrier is 1,000 kc. This means that there will be 1,000,000 complete cycles every second. The amplitude of the carrier reaches a peak at $+E_1$ and a negative peak at $-E_1$. The same positive and negative peaks are reached during each cycle. Thus, there is no change in the amplitude of a carrier from one cycle to the next.

Two audio-frequency signals are illustrated in Fig. 27-2b. By means of the circuits used in a radio transmitter, the audio signal is combined with the radio-frequency carrier. When the two waves are combined, the result looks like the waveform shown in Fig. 27-2c.

Notice that where the a.f. and the r.f. have been combined, the outline of the resulting wave corresponds with the outline of the a.f. This outline of the combined wave is called the *envelope*. The envelope has two identical halves, one-half above the zero axis and the other half below the zero axis. These halves are opposite in polarity. The process of putting an audio-frequency envelope around and r-f carrier is called *audio modulation*. Where the amplitude of the information is great, the amplitude of the entire envelope is great. Where the amplitude of the a.f. is low, the amplitude of the envelope is low. Where there is no a.f., there is no modulation of the carrier and its amplitude remains constant, as shown between points 1 and 2 in Fig. 27-2c. Unmodulated portions of the carrier result in no sound at the loudspeaker of the receiver, even though it is tuned in to the station sending out that particular carrier.

Also notice that the envelope is on both sides of the carrier and that the amplitude of the modulated carrier is sometimes greater than the amplitude of the carrier alone. In order to understand these facts and other aspects of the modulation process, let's study what happens in the transmitter itself. Figure 27-3 is a combined simplified schematic and block diagrams of the last stages of the transmitter.

Let's consider the upper two blocks—the oscillator and the r-f amplifier, as if the lower two blocks were not in the circuit. The

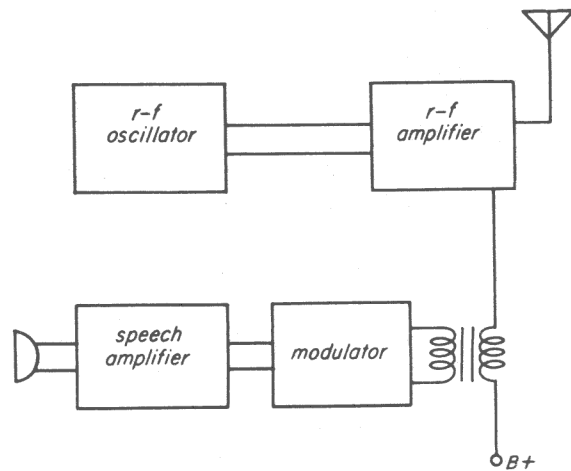


Fig. 27-3

oscillator can be regarded as a generator with an output of r-f frequency. The output of the oscillator is amplified by the r-f amplifier. Under certain conditions it is known that the amount that the signal is amplified depends upon the gain. The gain, in turn, depends upon several factors, one of which is $B+$. If $B+$ is increased and no other factor changes, the gain of the amplifier increases.

Let's suppose that the value of $B+$ is such that the gain of the r-f amplifier produces an output that has the amplitude shown in Fig. 27-4a. Also, let us suppose that doubling the $B+$ increases the gain so that the output has the amplitude shown in Fig. 27-4b. Further, let's suppose that cutting the $B+$ in half reduces the gain so that the output has the amplitude shown in Fig. 27-4c. We now have a situation in which the amplitude of the r.f. varies with the $B+$.

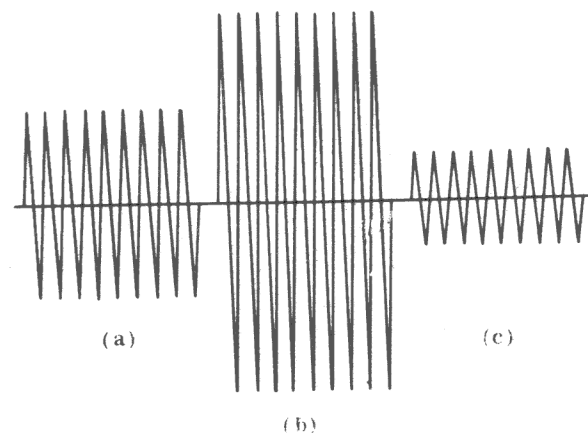


Fig. 27-4

Now, let's consider the third block in Fig. 27-3. The output of the audio amplifier, either adds to or subtracts from the $B+$ of the r-f amplifier. Thus, the $B+$ increases or decreases in the same pattern as the output of the a-f amplifier. Therefore the output of the r-f amplifier has the same pattern as the audio output.

Now that we are acquainted with the process of modulation, let us find out about detection (also known as *demodulation*). At the radio receiver, we want to change the waves back to the original a-f signal and discard the carrier completely so that only the a-f signal remains.

The envelope can be divided into two halves—the half above the zero axis and the half below the zero axis. The two halves are symmetrical; that is they have the same shape and amplitude. However, the two halves are opposite in phase. If both halves were to be applied directly to a pair of earphones or a loudspeaker, the halves would cancel each other out. While one half envelope was tending to move the loudspeaker cone in one direction, the other half, being opposite in phase, would tend to move the cone in the opposite direction. The net result would be no movement of the cone.

However, the cone would move if the two halves were not symmetrical. If one half of the envelope had the original signal pattern

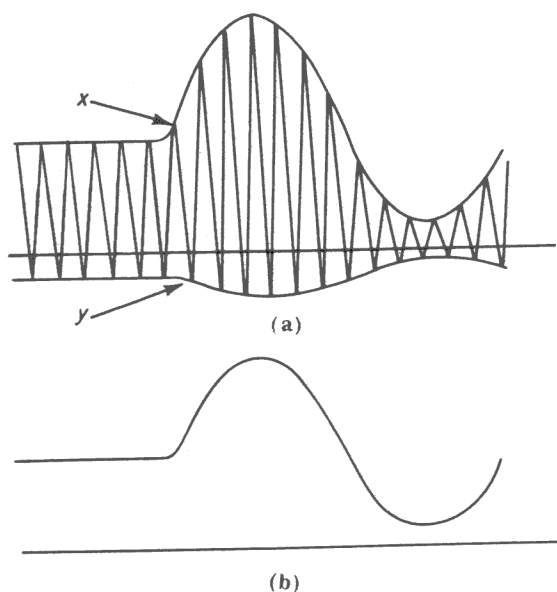


Fig. 27-5

and the other half had a *lower amplitude* with the same pattern, and the entire envelope were applied to a loudspeaker, the cone would move for the following reason: As the larger half-envelope was trying forcefully to move the cone forward, the smaller half would be trying weakly to move it backwards. The larger force would overcome the weaker opposing force. The cone would move as though it were driven by a single half envelope whose amplitude was equal to the difference between the undiminished half envelope and the half envelope with the reduced amplitude. The waveform that results from the difference between the two half envelopes in Fig. 27-5a is shown in Fig. 27-5b. This difference envelope could be used to operate the loudspeaker.

However, the amplitude of this difference is less than the amplitude of the original half envelope, as you can see by comparing the waveforms in Fig. 27-5. Some of the amplitude of the original signal has been lost. It would be more efficient to use all of the amplitude of half X. This can be done if half Y is cancelled out altogether.

27-2. DIODE DETECTORS.

Figure 27-6a is the schematic diagram of a simplified diode detector circuit. The tube shown in this circuit is a diode. However, it is possible to use a triode if two of the three elements are tied together, or even a multi-element tube if its elements are tied together so that it works as a diode.

You have learned from your study of diodes that they are used for rectification. You have just learned that it is necessary to rectify the modulated r-f carrier in order to get rid of half or somewhat less than half of the envelope. So the diode tube in a diode-detector circuit performs one of the fundamental parts of detection—rectification.

Fig. 27-6b shows an input voltage that could be applied to the diode detector circuit and 27-6c shows the output voltage after it has been rectified by the diode. Half the envelope has been discarded. However, this rectified waveform is still a signal of an r-f frequency. What we want is to discard the r-f component, (the pulses) and retain only

the a-f component (the outline). This function is performed by C_1 and R_L , the load on the diode detector. Let's consider the whole operation in greater detail.

The secondary of the input transformer, L , and the capacitor, C , form a tuned circuit that is resonant at the frequency of the incoming wave. The incoming wave is a.c., so the diode plate is alternately positive and negative. When the plate is positive, the

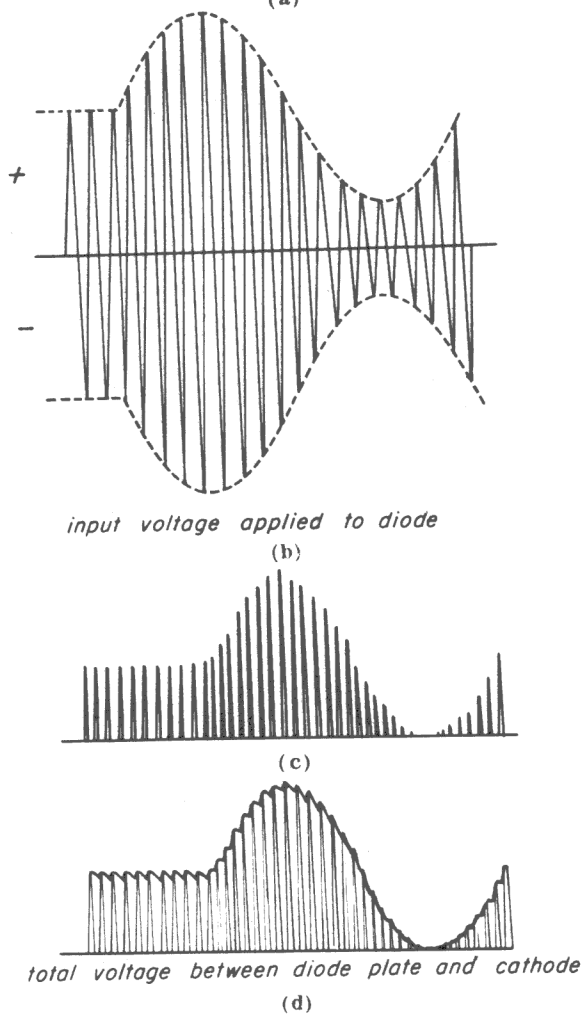
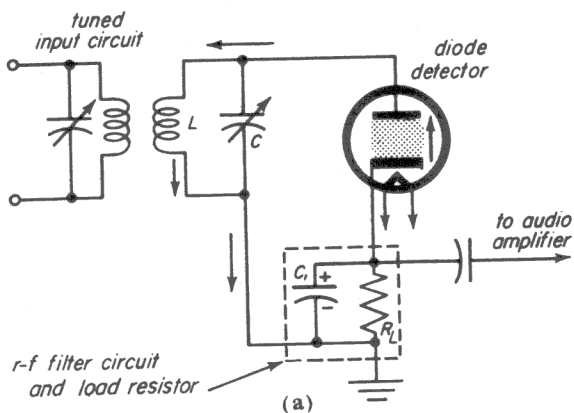


Fig. 27-6

diode conducts; and when it is negative, the diode does not conduct. As a result, the negative envelope is eliminated and the input is rectified.

If C_1 were omitted, so that only R_L were between cathode and ground, the waveform across R_L would be a series of positive half cycles, or pulses, as shown in Fig. 27-6c. But the charging and storage action of C_1 , and its slow discharge through load resistor, R_L , alter the output waveform so that the voltage variations at the top of the load resistor R_L have the waveform shown in Fig. 27-6d.

When the tube conducts, a voltage appears across capacitor C_1 and resistor R_L , which comprise a simplified filter and load circuit. Let's consider in detail the action of this simplified filter upon the rectified output of the detector. A few cycles of this waveform are shown in Fig. 27-7a. During the half cycle that the diode is conducting, the voltage across the capacitor C_1 rises until the voltage reaches its peak. This rise is shown between points A and B. Then as the voltage begins to fall, and during the next, or non-conducting half cycles, the capacitor begins to discharge slowly, through R_L , the load. It cannot discharge swiftly because R_L has a high resistance. The partial discharge of the capacitor is shown between points B and C; the time constant of the circuit (C_1, R_L) is such that the capacitor does not have time to discharge completely. By the time it has discharged as far as point C, the next positive half-cycle has started and the rectified voltage has risen enough so that the capacitor begins to charge again, until the voltage reaches its peak again at D. Then, as the voltage falls again, the capacitor begins to discharge again and the process is repeated.

In Fig. 27-7b the effect of the filter circuit is shown. Because the charge on the capacitor remains close to the peak, most of the r-f component, shown by lighter lines in the figure, is eliminated. It is blended into a pulsating d.c. (The charge on the capacitor cannot fall to zero during the nonconducting half cycles because the capacitor does not have a low-resistance discharge path.) If the capacitor were not in the circuit, the voltage at the cathode would fall

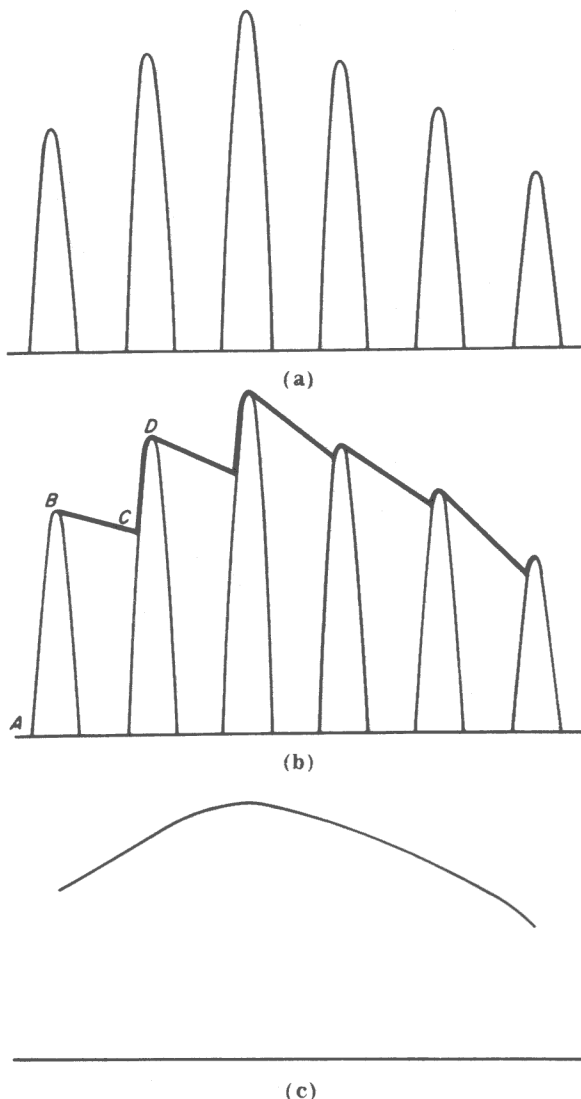


Fig. 27-7

to zero on every non-conducting half cycle. However, the capacitor, which charges up as a positive half cycle rises to its peak, starts to discharge slowly as soon as positive half cycle goes below its peak. It can continue to discharge only until the next positive half cycle rises to a level of voltage equal to its charge at that instant. Then it begins to charge again. On high peaks it charges to a high level. When the peaks begin to diminish, the charge diminishes with them. The resulting waveform (which is also the charge on the capacitor) just about follows the line of the envelope. The little notches of r.f. that still remain in the waveform shown in Fig. 27-7b are removed by subsequent filtering. The result is the clean audio signal shown in Fig. 27-7c. It is this signal that is fed to an audio amplifier.

The values of C_1 and R_L must be chosen to have the correct time constant. With the correct time constant, capacitor C_1 will be charged to peak value on the first r-f pulse. If the time constant is much too long, the charge on the capacitor cannot vary rapidly enough to follow the variations of higher audio frequencies (e.g., 10 kc) without reducing their normal amplitude. Therefore, the output of the detector cannot resemble the original a-f modulation. If the time constant is too short, the capacitor may charge and discharge completely during a single pulse. As a result, the output of the diode detector circuit will be simply rectified r-f.

Therefore, the time constant should be longer than the duration of an r-f pulse and shorter than the duration of the highest a-f pulse.

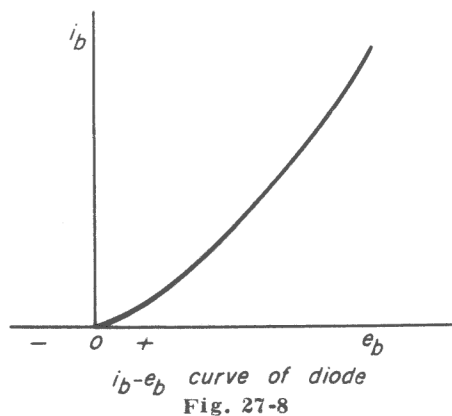
The capacitance of C_1 should be at least from five to ten times higher than the inter-electrode capacitance of the tube. As a result, the capacitive reactance of the tube at the frequency of the rectified current will be much greater than the reactance of C_1 . This high reactance, and the fact that the tube does not conduct in the reverse direction, combine to keep the tube from draining off the charge on C_1 .

The output of the diode detector is taken off the load resistor, which is R_L in the circuit shown in Fig. 27-6a. This resistor is in series with the internal resistance of the tube; the two resistances together form a voltage divider. The larger the resistance of R_L in proportion to the resistance of the diode, the greater is the proportion of the total voltage drop across it. Therefore, in order to get a large voltage output from the detector, it is necessary to have R_L be of a relatively large value. In practical diode-detector circuits, the value of R_L ranges from about 250 k-ohms to 1 megohm. When R_L is of such a high value, the d-c voltage drop across R_L , which is the value of the output of the diode detector circuit, is almost equal to the value of the peak amplitude of the carrier input. Therefore, the diode is efficiently rectifying the carrier. Commercially used diode-detector circuits have an efficiency of 75% or more, depending upon the value of R_L .

In addition to the audio signal, the diode detector also develops a *d-c voltage* across R_L and C_1 . The positive r-f pulses, prevented by C_1 from falling to zero, constitute a d-c voltage upon which the audio signal and the r-f remnant (notches) are superimposed. This d-c voltage will be large for strong carrier signals, and small for weak ones. It will be proportional to the carriers. Note the polarity. The cathode end of R_L is positive, the other end negative.

Fidelity. We can use a plate voltage versus plate-current curve, such as the one in Fig. 27-8 to find out about important aspects of the diode detector. This curve is almost a straight line. Therefore, for most values of plate voltage, the plate current will be in proportion to plate voltage. The input to a diode detector is a varying plate voltage. The output audio signal is the varying voltage drop across R_L caused by varying plate current. Therefore, when the diode in the detector circuit is operated on the straight-line portion of the curve, the demodulated signal will be very much like one-half the envelope that reached the input of the tube. Stated in other words, the detector will reproduce the signal with excellent fidelity.

Only the lower part of the i_b-e_b curve is not straight. That means that only relatively low input voltages will not be reproduced with good fidelity at the output. To offset the distortion of weak input signals, most radio sets amplify the incoming signal before it reaches the diode detector. As a result, all signal levels are strong enough to operate the diode on the linear portion of its curve.



Signal-Handling Ability. If the i_b-e_b curve of a diode were extended far above the point where it ends in Fig. 27-8, it would no longer be straight. It would turn to the right and become horizontal at saturation. However, practical values of input signal are within the linear part of the curve. Therefore, the diode will perform with excellent fidelity under practical conditions, even with very high input signals. So we speak of diode detectors as having excellent input ability.

Sensitivity. Since diodes have no gain, there is no amplification of the input. As a matter of fact, the output of a diode detector is less than the input. However, low sensitivity is not an obstacle to the use of diode detectors in commercial radio and television sets. Tuned amplifiers before the detector and audio amplifiers after the detector raise the signal to such a level that the loss in the diode is offset.

Selectivity. The input to the diode tube comes from a tuned circuit. The coil in this tuned circuit is the secondary of the detector input transformer. The selectivity and voltage of the tuned circuit are highest at resonance when the impedance of the circuit is highest. But the impedance of the diode tube is in parallel with the impedance of the tuned circuit. Since the diode tube draws current from the circuit, it is like a low resistance in a parallel with the tuned circuit. As a result, the output voltage and the selectivity of the tuned circuit are reduced.

In practical radio circuits, tuned amplification before the diode detector is more than sufficient for satisfactory reception. The lower output and poor selectivity of this one stage, resulting from the fact that the diode draws current, is offset by the selective amplifier stages preceding the detector.

Other Types of Diode Detectors. The diode detector circuit shown in Fig. 27-6a is not the only possible version. For example, the diode detector might be combined with a triode amplifier in the same circuit, as shown in Fig. 27-9.

This is a good circuit to consider for the purpose of becoming familiar with actual cir-

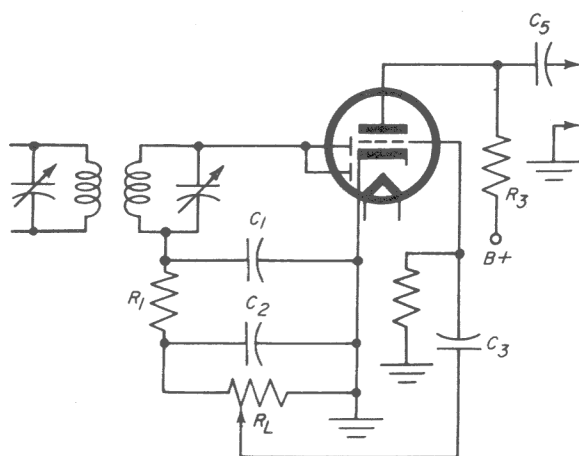


Fig. 27-9

cuit conditions in which one tube is used for more than one purpose. The tube used in the circuit illustrated is a duo diode-triode. Let's consider the operation of the detector portion first.

Just as in the diode detector that you have already studied, the diode tube and its load are connected across a tuned circuit, the coil of which is the secondary of a transformer. Because the tube used in this circuit has two diode plates and we require only one plate, the plates are tied together. (Later, in discussing other diode detector applications, you will see another application in which the two plates are not tied together.)

Furthermore, as in the diode circuit you have already studied, the diode rectifies the incoming audio-modulated r-f wave. The major difference between the circuit in Fig. 27-9 and the one you have already studied is the r-f filter circuit and the ground connection, which now goes to the cathode end of R_L . The r-f filter circuit in the illustration consists of capacitor C_1 , resistor R_1 and capacitor C_2 . You may recognize this as a pi-type filter circuit. This pi-type filter provides a smooth audio output with much less left-over r-f than the simple filter shown in Fig. 27-6a. (If you do not remember how this type of filter operates, review the Theory Lesson on filters.)

The output voltage of the detector circuit in Fig. 27-9 appears across the load potentiometer R_L , which is the volume control of the radio set. The audio signal is

coupled by means of coupling capacitor C_3 to the grid of the duo-diode-triode. The varying signal on the grid is amplified and coupled to the next stage—the power output stage.

The detector-amplifier circuit of the type that you have just studied is the one most commonly used in commercial radio sets. Tubes such as the 6Q7, 6SQ7, and 12SQ7, and miniature tubes such as the 6AV6 and 6AT6 are some of the electron tubes that have been developed for this type of detector-amplifier circuit.

Automatic Volume Control. The detector circuit in Fig. 27-9 has an output that is fed only to the audio amplifier. But more than one output may be taken from the diode detector circuit. For example, in Fig. 27-10, which uses the same basic circuit as Fig. 27-9, the audio output goes to the volume control and amplifier, whereas the d-c voltage at point A, is tapped off through an additional filter circuit whose output is labeled, *avc*. The letters *avc* stand for *automatic volume control*.

Before we consider exactly what the *avc* circuit does, let's review some of what we know about the incoming signal. We know that a signal from a station to which a radio receiver is tuned may not come in at a constant strength.

The volume control may be set to a particular level, yet the signal strength will vary due to a fading out of the carrier wave.

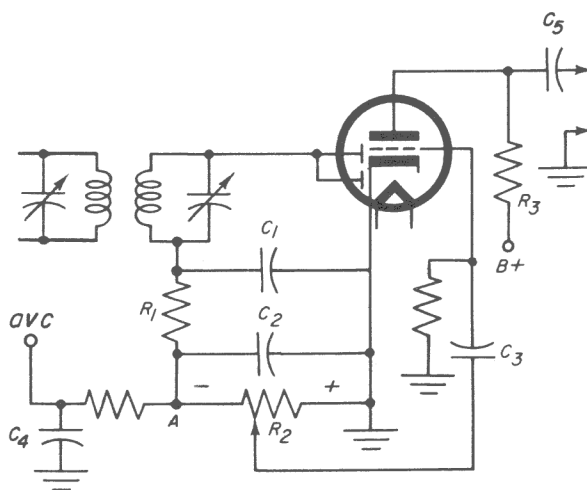


Fig. 27-10

There may be a blast of loud volume when the set is tuned from a weak signal (for which the volume control has been turned high) to a strong signal. Or there may be a loss of signal when the receiver has been tuned in on a temporarily high signal and is then tuned to a weak signal.

Furthermore, with the volume control set at a particular position, one station with a constantly strong signal may be heard very loud. Another station with a weak signal may be heard only faintly.

It is desirable to have the signal level more constant. This is done by regulating the gain of the r-f and i-f amplifiers of the radio receiver so that there is much less gain for a strong signal than for a weak signal. This is done by means of a negative d-c voltage called the *control voltage*. This control voltage is obtained by passing the d-c output of the detector through an audio filter, such as the one shown in Fig. 27-10, and by applying the negative voltage to the control grid of preceding tuned amplifier stages.

The way in which this is done is shown in Fig. 27-10. Notice that the cathode of the duo-diode triode is grounded. This means that the positive end of R_2 is grounded. The other end of R_2 is therefore negative with respect to ground. Now let's consider the flow of current in the circuit. The tube conducts only when the diode-plate side of the tuned circuit is positive. When the tube is conducting, a d-c voltage with the polarity shown develops across R_2 . If the d-c voltage is taken off at point A of the circuit, the voltage will be negative with respect to ground and proportional to the strength of the signal.

The voltage at point A is applied to the grids of the preceding tubes through the avc filter, the purpose of which is to filter out the relatively rapid audio voltage variations but to pass gradual changes of the d-c level. The time constant of the filter is chosen to allow slow variations of the charge on C_4 , but not rapid variations. Thus, as the station gradually fades, the slow change in d-c control voltage can be applied to the control grids, but the audio variations can not. A

strong signal makes the control grids more negative, reducing the gain of the stages preceding the detector. A weak signal makes them less negative so that gain is higher. Thus gain is controlled by the incoming signal, and varies in a way that keeps the input to the detector fairly constant for wide differences in carrier strength.

Linearity. One way of considering detectors is to divide them into linear and nonlinear types. We have already considered the linear type—the diode detector. The diode detector is called linear because it completely eliminates one half of the carrier envelope—either the negative or the positive half cycle, depending upon the circuit used. This is called *complete suppression*. Since one half is completely eliminated, the audio output follows the envelope of the other half exactly. However, a detector may eliminate less than one half of the carrier envelope. Such a detector is termed nonlinear. Because it reduces one envelope greatly, without reducing the other, the two envelopes are no longer equal and opposite. They do not cancel completely. The weak one cancels a small amount (equal to itself) of the strong one. The remainder of the strong one contains the audio signal. When the second half envelope is not eliminated completely, the condition is called *incomplete suppression*.

Since it is usually desirable to have complete suppression in commercial radio receivers, diode detectors are most commonly used. However, nonlinear detectors are also used for special purposes.

27-3. CRYSTAL DETECTORS

The simplest nonlinear detector is the crystal detector, which was one of the first types used in radio receivers. This type of detector uses a crystal diode. The crystal, which may be made of silicon, galena, carborundum (silicon carbide), iron pyrites, or specially treated germanium is mounted in a soft metal holder. A wire with a sharp point, called the catwhisker, is in contact with a point on the surface of the crystal.

The crystal has an unusual quality when current is sent through it. Roughly, current

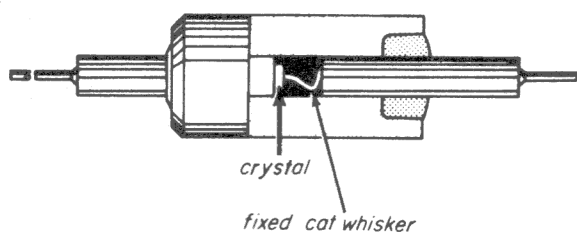


Fig. 27-11

sent through the crystal shown in Fig. 27-11 will flow from the crystal to the catwhisker 10 times more readily than in the reverse direction from the cat-whisker to the crystal.

Note: Do not confuse this application of the crystal with applications of piezoelectric properties of quartz or Rochelle salt crystals.

The detector crystal is used in a circuit of the type shown in Fig. 27-12. With r-f polarity as shown, current flows through the junction readily. When the polarity of the input signal is reversed, current flows with great difficulty.

Let's see how this looks on a curve. In Fig. 27-13, the curve for a crystal's response is plotted. The X axis is used to show the voltage applied to the crystal and the Y axis shows the current that could be measured through load resistance or impedance. Notice that, unlike a curve for an electron tube, the curve for a crystal goes below the X axis—that is, a voltage with negative polarity is shown forcing current through the crystal. But it is much smaller than the current flow, for equal applied voltage, in the opposite direction. This negative-going portion of the current curve levels off at a point slightly below the X axis.

Since cat-whisker junctions conduct much more in one direction than in the reverse direction, the current through the crystal is much greater when a voltage is applied in one direction than when a voltage is applied in another direction.

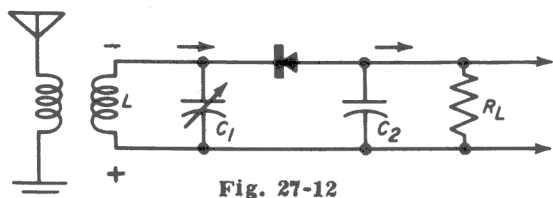


Fig. 27-12

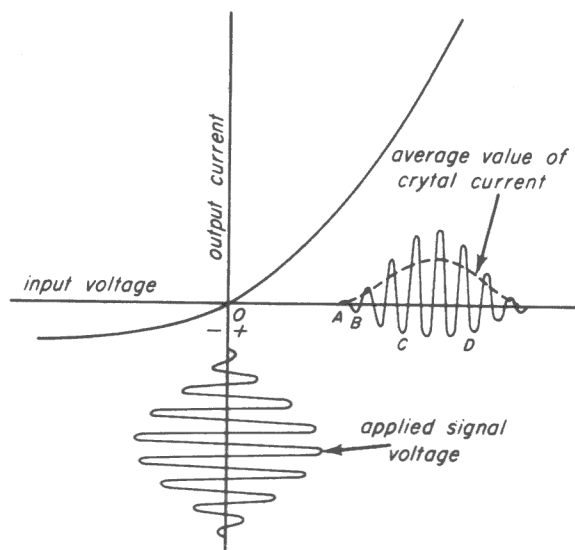


Fig. 27-13

In the load, R_L , the small current will cancel part but not all of the larger opposing current. The remainder of the larger current, or the resultant current, will vary with the audio modulation. The dashed line in Fig. 27-13 shows the resultant. It will produce a varying voltage drop — an audio voltage — across R_L .

The capacitor C_2 eliminates the r-f component, just as in the similar diode circuit. But it does not charge to the peaks. It charges to the level of the positive peaks minus the negative peaks, that is, to the level of the resultant.

The input signal is shown starting at zero and swinging alternately negative and positive. The output current is plotted just as on electron-tube curves. From the shape of the curve, we can see that the positive swing of the applied signal causes a greater output. The negative portion of the input causes operation on the nearly horizontal portion of the curve. As a result, the negative swings of the applied signal produce little current in the load. This is an example of nonlinear operation.

Because some of the negative portion of the applied signal appears at the output of the crystal detector circuit, that is, because

the lower half of the r-f signal (or sometimes the upper half) is not completely eliminated or suppressed, we have what is called *incomplete suppression*.

Up to this point, we have been considering only the rectification that occurs. The filtering from the audio signal of the leftover r.f. is accomplished by C_2 . With the proper time constant for R_L - C_2 , C_2 levels out the rectified r-f voltage across R_L . The charge on the capacitor responds to the outline of the resultant output voltage peaks—that is, to the audio variations.

Notice in Fig. 27-13 that this process introduces distortion. The proportion of the original negative input that is rectified depends upon the amplitude of the signal. For example, the cycle from points A to B is less distorted (the lower half of the cycle is less) than the cycle from points C to D.

Certain improvements have been made in the crystals that are used in crystal detectors. The catwhisker type, which has been used for many years, must be carefully adjusted so that the catwhisker is at the point on the crystal that gives the greatest response. Vibration may cause the catwhisker to shift.

One way in which this difficulty has been overcome is by fixing the catwhisker in place in the germanium diode shown in Fig. 27-11. This crystal, made of germanium with some desirable impurities added, is used widely. One of its advantages is that it has a high forward to back ratio of conductivity—much more current flows forward than backward compared to crystals used earlier in the development of radio receivers. As a matter of fact, the detection has such good linearity—that is, the curve for the germanium crystal is so linear and, as a result, the distortion is so small, that the output of the germanium is almost as linear as that of a diode tube.

Silicon diodes are used in place of germanium diodes where high heat is encountered because silicon is more stable at high temperatures.

Crystals are used for detection in applications such as miniature equipment, where small size is an advantage. Because crystals have less capacitance between their terminals than the interelectrode capacitance that is found in the diode tubes used as detectors, and because electrons have smaller distances to travel in crystals, crystal detectors are used for UHF circuits.

Another feature of crystal detectors is that crystals do not require a heater supply. As a result, there is no danger of introducing heater current hum into high impedance circuits in which crystals are used.

27-4. GRID-LEAK DETECTORS.

Because of its high sensitivity, the grid leak detector was widely used in early receivers. It is still used today, though for special applications only. It is well worth study because of the many fundamental principles of electronics involved in its operation.

Fig. 27-14a shows a simple grid-leak detector circuit. It is really two circuits—a modified diode detector and a simple audio-voltage amplifier. One type is shown in Fig. 27-14a and another in Fig. 27-14b.

The grid-cathode portion of the grid-leak detector circuit is just another version of

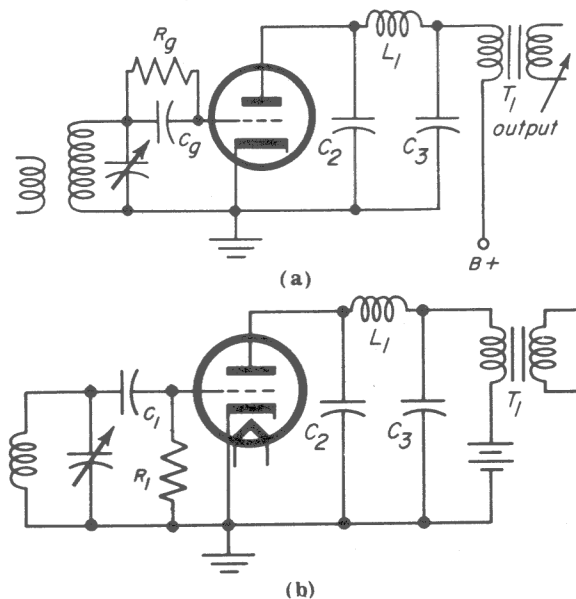
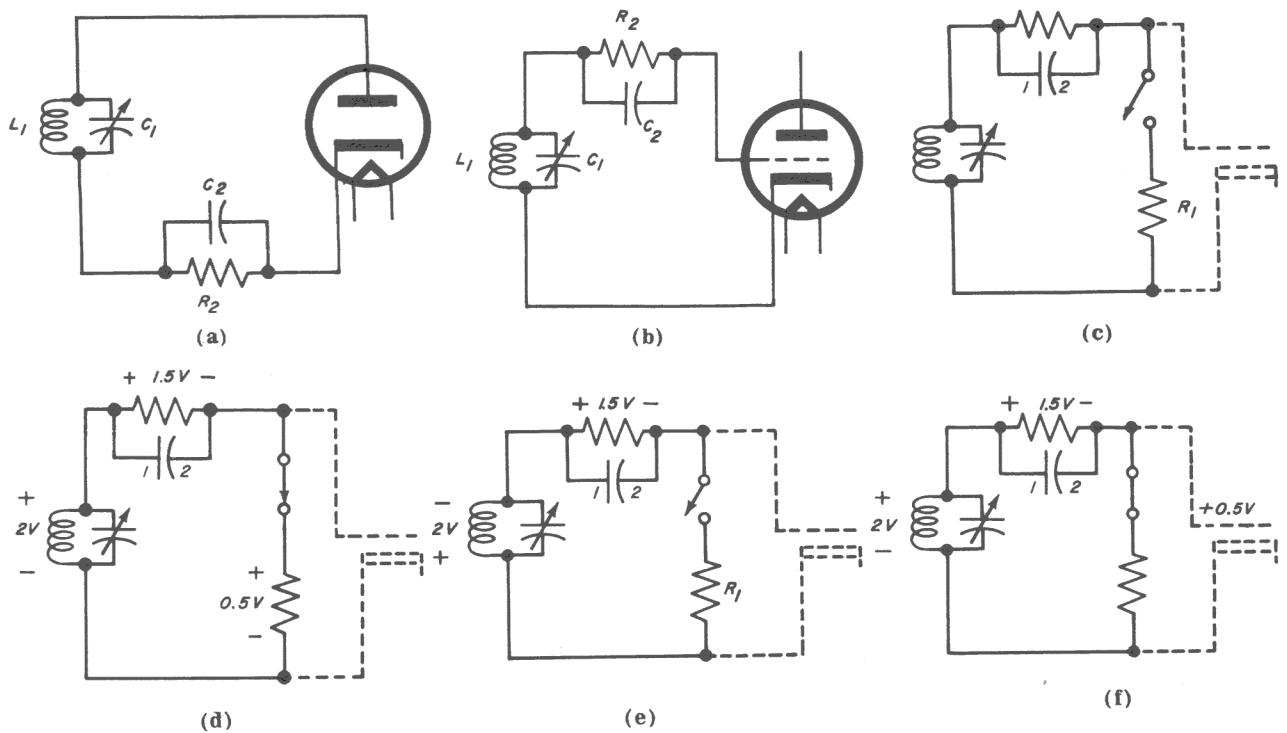


Fig. 27-14



action of grid-leak input circuit

Fig. 27-15

the simplified diode circuit shown in Fig. 27-15a. If we move the R-C load to a new position, and substitute a grid for the diode plate, the circuit is as shown at b in the figure. (Let's forget the triode plate for the time being.) If an incoming carrier applies a positive r-f half cycle to the grid, making it momentarily positive, the grid will behave like a diode plate — it will attract electrons emitted by the cathode. A current will flow between cathode and grid. The electron stream will be a low impedance path between cathode and grid, a path equivalent, during the time that the tube conducts, to a low-value resistor. During the next half of the r-f cycle, a negative pulse will be applied to the grid. No current will flow between grid and cathode. The path between cathode and grid will no longer be like a low resistance. It will be like an infinite resistance, like an open circuit.

The equivalent circuit may be represented by showing a switch and a low-value resistor R_1 , in place of the cathode-to-grid electron stream, as at c in the figure. Whenever the top end of L_1 is positive, the switch is closed. When the top of L_1 is negative, the switch is open. Suppose a positive r-f cycle of 2 volts peak is applied to L_1 ; the top of

L_1 will be positive with the switch closed. Most of the 2 volts will be impressed across C_2 and a small part across R_1 . Suppose the average voltage across R_1 during the half-cycle is 0.5 volt. Then 1.5 volts will be across C_2 , and will represent the charge on C_2 , with the polarity shown at d. The grid side of C_2 , plate 2, is shown negative. It is negative only with respect to the other plate 1. With respect to ground, or cathode, plate 2 is at the moment 0.5 volt positive, for it is connected to the upper end of R_1 . However, it becomes negative with respect to ground and cathode on the next (negative) half cycle, when the switch is open and plate 2 is no longer connected to low resistor R_1 . Now its 1.5-volt charge, with polarity as shown, is in series with the 2 volts peak of the negative half cycle, as shown at e. The voltage on the grid rises to -3.5, or nearly. Actually, C_2 discharges very slightly through R_2 . During one negative half-cycle, C_2 loses only a little of its charge because the discharge time is short, and R_2 is high.

On the second positive half-cycle, as shown at f, less positive voltage on the average will be applied to the grid because C_2 is now partly charged, and the polarity of C_2 bucks the

polarity of L_1 . Only the difference, 0.5 volt, will be applied as a positive potential at the peak of the cycle, attracting electrons to the grid. (The average positive voltage during the cycle will be less than 0.5 volt.) Fewer electrons will flow between grid and cathode, so that the path will be a higher impedance than before, and equivalent resistor R_1 will be higher. Because of the much lighter current through it, the voltage drop across R_1 will be less than before, perhaps only 0.2 volt. The charge across C_2 will rise only slightly, to 1.8 volt (2 impressed volts minus 0.2 volts across R_1).

With each succeeding r-f cycle, the charge on C_2 will rise further towards the peak level until after several cycles it will equal peak volts, minus the tiny loss through grid-leak resistor R_2 . Thereafter, it will remain constant unless peak level changes. If peak level rises, the charge will follow it up to the new peak. If peak level falls, the charge will follow it down to the new peak, because more charge can leak away through R_2 if each succeeding peak is smaller and cannot replace the amount of charge lost through R_2 during non-conducting half cycles.

The peak level will change. It will vary with the audio modulation of the carrier's envelope. The charge across C_2 will vary accordingly. The bias on the grid is the charge on C_2 . As the charge varies, the bias varies, at an audio rate.

Now, if we remember that there is a plate in the tube, (Fig. 27-14) with B+ supplied to the plate through a load impedance, we can see that the varying grid bias will vary the plate current through the load impedance. A varying voltage drop across the plate load impedance will be an amplified reproduction of the audio voltage on the tube's control grid.

A small remnant of r.f. from the carrier appears at the plate; but it is eliminated by the pi-type filter (C_2 , L_1 , C_3), a low-pass filter that rejects r.f. but lets a.f. through to the a-f transformer T_1 . The recovered audio is coupled to the grid of the next stage by T_1 .

27-5. PLATE DETECTORS

In plate detection, the audio signal is recovered by operating the tube at or near cut-off. Let's examine the circuit in Fig. 27-16. The value of the cathode bias resistor, R_1 , is so chosen that the operating point of the tube is close to cut-off. C_1 is large and holds the cathode at ground potential for r-f and a-f signals, thereby avoiding degeneration. When the grid side of the tuned input circuit is positive, the grid becomes more positive, and the tube conducts. When the grid side of the tuned input circuit is negative, the grid becomes even more negative than cut-off bias, and the tube does not conduct. As a result, only the positive half cycles produce an output. Thus one half of the r-f envelope is eliminated and the incoming signal is rectified. The smaller r-f filter capacitor, capacitor C_2 , in the plate circuit, smooths out the r-f pulses in much the same way as the capacitor across the diode load of Fig. 27-6a. Its capacitance is so chosen that the charge across it cannot vary much at the r-f rate, but can vary readily at an audio rate. Additional filtering in the following audio amplifier removes any left-over r-f not fully removed by C_2 .

The plate detection process can be shown by means of a curve such as the one in Fig. 27-17. The operating point of the tube is slightly above cutoff, which is the actual condition of practical plate-detector circuits.

A plate detector is not as free of distortion as a diode detector. Furthermore, AVC cannot be tapped off a plate detector. As a

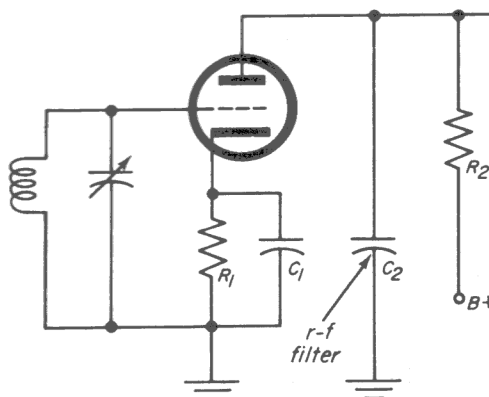


Fig. 27-16

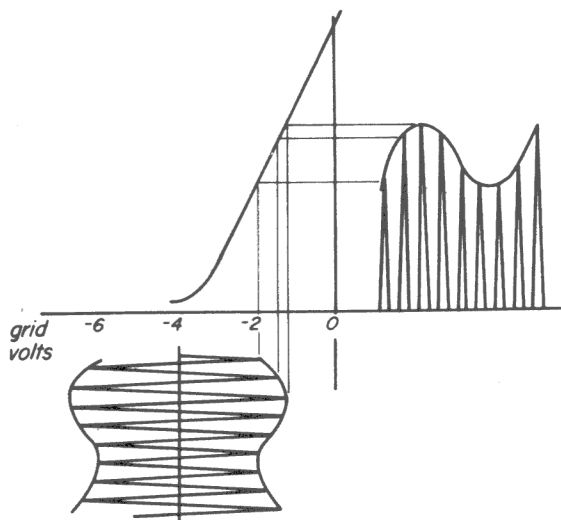


Fig. 27-17

result, plate detectors are not often found in commercial radio receivers.

27-6. REGENERATIVE DETECTORS

Regenerative detectors use feed-back to increase gain. The schematic of a regenerative detector shown in Fig. 27-18 shows how this type of circuit operates. Notice that the grid circuit resembles the grid circuit of a grid-leak detector. As a matter of fact, this circuit is a grid-leak detector and produces an amplified audio variation in the plate current. R-F pulses also appear in the plate current. There is a coil, L_1 , in series with the plate of the triode. The r-f pulses in the plate current passing through this coil produce an r-f field around this coil. The field induces a voltage in L_2 . The induced voltage in L_2 is in phase with the signal being transferred to L_2 from L_3 , the primary of the input transformer. The two voltages add together.

The amount of voltage fed back to the grid of the tube depends on the amount of

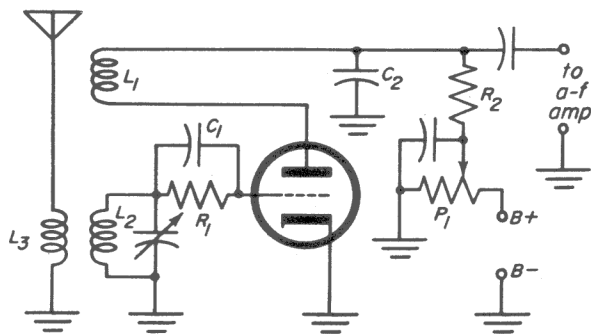


Fig. 27-18

magnetic coupling between L_1 , the feedback coil, and L_2 , the coil of the tuned input circuit. When this coupling is such that the voltage fed back is greater than the amount lost due to the ohmic resistance of L_2 , the amplification of the signal will keep increasing until the tube begins to *oscillate*. You will learn about oscillation in a later lesson. At this point, the important thing to know is that oscillation is not desirable in a detector of this type.

The degree of coupling is adjusted so that the amount of energy fed back is almost, but not quite, enough to start oscillation. At this point the energy fed back from the plate circuit is almost enough to completely cancel the grid circuit losses. The Q of the circuit becomes very high, and the gain is proportionately high. A regenerative grid leak detector yields about 100 times as much output on weak signals as does a plain grid-leak detector.

Note the location of C_2 , the r-f filter. It is not on the plate side of L_1 . If it were, r-f pulses appearing at the plate would be by-passed directly to ground, without first flowing through L_1 . They would not then create a varying magnetic field around L_1 . There would be no feedback and hence no regeneration.